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THE QUANTIFICATION OF HUMAN RELIABILITY

A Feasibility Demonstration

by

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Title Page

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TITLE

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ABSTRACT The purpose of this study was to demonstrate a method of calculating the probability of human errors during prelaunch testing. Completion of studies described herein will permit the following statements: (a) The probability that the test can be completed without human error, (b) The probability that human errors will remain undiscovered, (c) The probability that undiscovered errors will result in failures.

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In addition to a reliability number for the total test, such studies will provide a breakdown of reliabilities for all human tasks in the test. Areas of greatest risk can then be pinpointed and corrective efforts focused on them. A proposed method for calculating system reliability is described. Development and application of this method will permit assessment of the contribution of each preflight test to over-all system reliability, and will also point out the need for adding or removing tests. This method takes into account the probabilities: (a) that the hardware was manufactured correctly, (b) that the hardware will not be damaged by human handling, (c) that the tests administered to the hardware will reveal all malfunctions, and (d) the inherent reliability of the hardware. Reliability thus determined would be a function of the following: $R = f(CI)$ where R = reliability, C = confidence, and I = inherent reliability.

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ABSTRACT

The purpose of the study reported herein was to demonstrate a method of calculating the probability of human errors during prelaunch testing activities. Completion of the studies described in this report will permit statements of the following type:

a. The probability that the test can be completed without human error.
b. The probability that human errors will remain undiscovered.
c. The probability that undiscovered errors will result in failures.

In addition to a reliability number for the total test, such studies will provide a breakdown of reliabilities for all human tasks in the test. With this breakdown, areas of greatest risk can be pinpointed and corrective efforts can be focused on them.

Section 3 of this report describes a proposed method for calculating system reliability. Development and application of this technique will permit assessment of the contribution of each preflight test towards over-all system reliability. It will also point out the need for adding or removing tests from the testing cycle.

This method takes into account: (a) the probability that the hardware was manufactured correctly, (b) the probability that the hardware will not be damaged by human handling, (c) the probability that the tests administered to the hardware will reveal all malfunctions, and (d) the inherent reliability of the hardware. Reliability determined by this scheme would be a function of the following formula

$$R = f(CI)$$

where R = reliability, C = confidence, I = inherent reliability.

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SECTION 1
INTRODUCTION

The purpose of this report is to describe a technique which permits the quantification of human reliability. Use of this technique will permit one to assess the consequences of human error on system effectiveness and to identify human tasks contributing the most to human unreliability.

The basic goal of human factors effort is to improve human efficiency This is done in three ways: human engineering of equipment, design of procedures, and training. The basic function of a human factors program is to predict problems involving the interface between man and machine. In the past, human factors personnel have made use of laboratory research results in a qualitative manner. In other words, statements were made to the effect that one condition is better than another without qualification as to just how much better. The techniques described in this report will permit quantitative predictions about human error rates.

There have been many attempts in the past to evaluate the human part of a system. Most of these attempts have resulted in qualitative methods of evaluation. For a short review of these efforts, see the first chapter of Payne and Altman (Reference 2).

The first method of actually quantifying human performance was devised in 1962 by Payne and Altman (Reference 2). Their method was devised to obtain an Index of Electronic Equipment Operability, and resulted in a central data store of reliability information regarding a large number of task elements (See Appendix A). By recombining these elements, it is possible to obtain the probability for successful completion of almost any operator task. Payne and Altman's technique is usually referred to as DATA STORE.

A few months later, L. W. Rook (Reference 4) reported on a somewhat similar method in use at the Sandia Corporation. Rook's work applies primarily to industrial production. Where Payne and Altman obtained reliability data from laboratory studies, Rook made use of records from actual industrial practice. Another difference in the techniques is that Payne and Altman provide data on the probability of a human error, whereas Rook extends his data to the probability of a human error plus the probability that this error will result in a failure.

About one year later, A. D. Swain (Reference 6) published an extension of Rook's work. The extension was titled "Technique for Human Error Rate Prediction" or THERP for short. THERP was intended primarily to predict the consequences of human error during military operations (see Appendix A). The use of THERP techniques permits the combination of hardware reliabilities with human reliabilities to determine the effects of human error on system performance.

The present paper is an extension of the above techniques into the area of system testing during a manufacturing cycle.

SECTION 2
DESCRIPTION OF THE STUDY

2.1 OBJECTIVE

The basic objective of this study was to demonstrate, in a concrete manner, the feasibility of using DATA STORE and THERP for test activities.

2.2 BACKGROUND

Before presenting a description of the current study, perhaps a brief explanation of the context in which the study was performed is in order.

During the manufacturing cycle of a space vehicle, certain tests are performed at given points. In general, there are three levels of testing: component, subsystem, and system. Component tests are designed to weed out all malfunctioning parts just after manufacture; upon completion of component testing, the parts are assembled into subsystems. Subsystem tests are then administered to find errors and malfunctions that have occurred during subsystem assembly as well as to determine subsystem functional compatibility. After successful completion of these tests, the entire vehicle is assembled and given a system test to ensure that the subsystems are functionally compatible and that no errors or malfunctions have been introduced during the assembly process. When these tests are completed the vehicle is shipped to the Pad and is launched.

To conduct this study, a short human task was required which had a well-documented reliability history so that validation of the findings would be possible. The subsystem test for a pneumatic stabilization subsystem was chosen because it met the above criteria and involved primarily console activities which could be analyzed more easily than other operations. The pneumatics system is packaged on a bulkhead that is

installed on the vehicle when the stabilization subsystem test has been completed. After installation in the vehicle, the pneumatics system is tested twice more: once during the system test and again during the field cycle prior to launch. These subsequent checks will provide validation evidence for the method under study, i.e., quantification of human performance.

2.3 SEQUENCE OF EVENTS

2.3.1 TASK ANALYSIS

After selection of the task to be analyzed, a complete and accurate task analysis was required. Subsystem tests are described step by step in a document called a Standing Instruction (SI); this SI was used as a starting place for the task analysis. It was believed, however, that the SI was not sufficiently detailed for a DATA STORE type analysis and so further study was required to add sufficient detail. Several visits were made to the pneumatics test cell to observe activities and talk with test personnel in order to become familiar with the human actions involved in the test. Dry runs of the test were witnessed and appropriate corrections and additions were incorporated into the task analysis as a result. The final activity in the test cell was an observation of an actual test of the pneumatics subsystem. Following this event, a final version of the task analysis was written and reviewed by test personnel.

2.3.2 INDEPENDENT TASK RELIABILITIES

Upon completion of the task analysis, the next required action was the assignment of reliabilities to the task elements. This was accomplished through use of the DATA STORE. (See Appendix B.) In some instances, DATA STORE values did not seem appropriate for the specific situation in which they were being applied. In these cases, changes were made to the DATA STORE values on the basis of "expert" judgment.

2.3.3 COMBINATION OF RELIABILITIES INTO ONE FIGURE

After individual steps in the task analysis had been evaluated, the process of combining these numbers into a single figure for the total test was begun. Use of the procedures recommended in DATA STORE assumes that all events in the test are independent of each other. This seemed to be the case in many of the steps but not in all of them. In those instances where tasks were not independent, the success probabilities of tasks were modified to reflect the true situation. Combination of the individual task reliabilities into a single success probability for the total test gave an estimate of correct "first trial" performance; i.e., the probability of not making a single human error.

2.3.4 PROBABILITY OF ERROR CORRECTION

The next step was the evaluation of the effects of operator errors. To do this, each step in the task analysis was reviewed with a Quality Control engineer to evaluate what types of errors were possible and what their effects would be. In general, operator errors are one of three types: those that are caught by the operator because he cannot continue the test; those that affect the recording made during the test and as such can be caught by the man checking that record after the test; and those that go undetected until some later point in the test cycle, or that result in a mission failure. Analysis of the effects of operator error revealed that the greater majority of human errors in the test would be caught and corrected by the operator himself. The result of these types of errors is an increase in test time to obtain the proper data.

In twelve instances, the probability of the operator correcting his error was less than a certainty; i.e., the error might go undetected (see Table 2, page 10). The engineer examining the test record usually has a high probability of detecting errors missed by the operator. In two instances, however, no evidence of operator error is present until some later point in the test cycle after the subsystem has been assembled on the vehicle.

In summary then, there are three methods of correcting operator errors: self correction by the operator; correction by the man reading the oscillograph record; and correction by some test later in the cycle. If the operator corrects his own error there is little or no effect on vehicle reliability. If the man reading the record finds an operator error, the test must be repeated. If a faulty valve or regulator is discovered after mating to the vehicle, a delay is incurred that is much more expensive in both time and money.

2.3.5 COMBINATION WITH HARDWARE RELIABILITIES

When one calculates the probability of human error, he is essentially determining the probability that a given test will be conducted properly. Because of this, human errors by themselves do not affect system success or failure. A human error can have serious consequences only if the man can damage the system by poor test techniques or if, as a result of poor test technique, he fails to discover a malfunctioning part.

To properly evaluate the effect of human error on system performance, the reliability of the equipment under test must be factored into the evaluation. Because of this, it was decided that the most meaningful statement to emerge from this study would be the probability of normally functioning equipment being on the vehicle when it undergoes system testing. In line with this philosophy, the reliability figures for high- and low-flow solenoids were obtained and combined with the probability of the test being conducted properly. When this calculation was made, the number that emerged was 0.9975. This value represents the probability of a non-malfunctioning set of valves being placed on the vehicle at the start of system testing. (See Tables 3 and 4, pages 11 and 12.)

For a malfunctioning valve to be placed on the vehicle, the following must be true:

a. A human error must occur.

b. This error must go undetected.

c. This error must be made on a test of a malfunctioning valve such that the test erroneously pronounces the valve to be good.

2.3.6 MATHEMATICAL RESULTS

This section will show the methods of calculating test reliabilities, as well as the results of the various calculations.

Table 1 (page 9) is a listing of the success probabilities for each step in the task analysis, along with the the total success probability for the first attempt. The success probabilities for each task were obtained by using the numbers contained in the DATA STORE. In most cases the values given in the DATA STORE for the various parameters of each subtask were combined by multiplication. This process assumes that all of the parameters are operating independently of each other.

For step 10e(1) of Appendix B (adjust potentiometer), a different method of combining probabilities was necessary. Normally, this potentiometer does not have to be adjusted since the required 5-volt setting is never changed. Occasionally, though, the value will drift or someone will move the control knob, making a voltage adjustment necessary. For purposes of the analysis, it was assumed that this task would have to be accomplished every fourth time the recorder was turned on. The method of calculating the success probability of this step was as follows:

a. Determine the success probability in the normal manner; i.e., use the values in the DATA STORE and combine them by multiplication.

b. Subtract the resulting value, 0.9980, from unity to find the probability of failure; i.e., 0.0020.

c. Take 3/4ths of this value; i.e., 0.0015.

d. Subtract this value from unity; i.e., 1.00 -0.0015 = 0.9995.

e. Substitute this value for the originally obtained value on the step.

f. Use this value in the normal manner for obtaining total success probability on step 10 (set up oscillograph recorder).

A similar method was used in the calculation of the success probability for steps 10f (set up traces on recorder) and 18b (set automatic delay timers).

Table 2 shows the probability of correcting operator errors. The first column lists the success probabilities for the first trial of each step in the task analysis. All items with success probabilities below 0.9900 are identified by asterisks. The second column shows the probability of the operator correcting errors performed on the first trial. Entries were made in this column only if the value was less than 1.000. As can be seen from the table, errors on only 12 of the steps are involved.

The third column represents the probability of the record reader noticing the error made by the operator. In most cases, the only corrective action open at this time is a rerun of the entire test.

Table 3 presents the data used to determine the probability of correcting errors. Those steps of the task analysis that have not been included in the analysis were omitted because the probability of their being discovered and corrected by the operator was 1.000 and, as such, they would not affect the final reliabilities. The

Table 1. Summary of Reliabilities from the Task Analysis by Steps

Step	Reliability	Step	Reliability
1	0 9960	24	0 8119
2	0 9886	25	0.9971
3	0.9722	26	0.8119
4	0.9745	27	0.9971
5	0.9977	28	0.9975
6	0.9985	29	0.9930
7	0.9991	30	0.9992
8	0.9985	31	0.9991
9	0.9985	32	0.9976
10	0.9711	33	0.9990
11	0.9038	34	0.9934
12	0.9992	39	0.8864
13	0.9900	40	0.9898
14	0.9929	41	0.9947
15	0.9976	42	0.9968
16	0.9865	43	0.8859
17	0.9901	44	0.9990
18	0.9908	45	0.9971
19	0.9990	46	0.9992

TOTAL 3681

The probability of successfully performing the functional test on the first attempt is 0.3681.

Table 2. Probability of Correcting Errors

Step	Probability of Correct First-time Accomplishment		Probability of Operator Correcting All Errors in Task	Probability of Recorder Reader Catching Errors
1	0.9960			
*2	0.9886		0.9900	1.00
*3	0.9722			
*4	0.9745			
5	0.9977			
6	0.9985			
7	0.9991			
8	0.9985			
9	0.9985			
*10	0.9711		0.9816	0.9990
*11	0.9038		0.9784	0.0100
12	0.9992			
13	0.9900			
14	0.9929			
15	0.9976			
*16	0.9865			
17	0.9901		0.9999	0.9999
18	0.9908		0.9976	
19	0.9990			
*24	0.8119	Steps 24 and 26 are combined		
25	0.9971			
*26	0.8119		0.9800	0.9900
27	0.9971			
28	0.9975		0.9508	0.9900
29	0.9930			
30	0.9992			
31	0.9991			
32	0.9976		0.9999	0.9999
33	0.9990			
34	0.9934		0.9999	
*39	0.8864	Steps 39 and 43 are combined		
40	0.9898			
41	0.9974		0.9999	0.9999
42	0.9968		0.9999	
*43	0.8859		0.9963	0.00
44	0.9990			
45	0.9971			
46	0.9992			

*Reliability below 0.9900

Table 3. Probability of Correctly Performing the Task *

Step	C_n	I_n	$R1_n$	$R2_n$	$I_n(R1_n)$	$I_n(R2_n)$	$C_n + I_n(R1_n)$	$C_n + I_n(R2_n)$
2	0.9886	0.0114	0.9900	1.00	0.0113	--	0.9887	1.00
10s	0.9990	0.0010	0.9990	1.00	0.0010	--	1.00	1.00
10e	0.9832	0.0168	0.9827	0.9990	0.0165	0.0167	0.9997	0.9999
10g	0.9934	0.0066	0.9999	1.00	0.0066	--	1.00	1.00
11	0.9038	0.0962	0.9784	0.0100	0.0941	0.0010	0.9979	0.9048
17	0.9901	0.0099	0.9999	0.9999	0.0098	0.0098	0.9999	0.9999
18	0.9908	0.0092	0.9999	1.00	0.0091	--	0.9999	1.00
20 thru 26	0.6572	0.3428	0.9800	0.9900	0.3359	0.3393	0.9931	0.9965
28	0.9508	0.0492	0.00	0.9990	0.0000	0.0491	0.9508	0.9999
32	0.9976	0.0024	0.9999	0.9999	0.0024	0.0024	1.00	1.00
35	0.9934	0.0066	0.9999	1.00	0.0066	--	1.00	1.00
41	0.9947	0.0053	0.9999	0.9999	0.0053	0.0053	1.00	1.00
42	0.9968	0.0032	0.9995	1.00	0.0032	--	1.00	1.00
43 & 39	0.7853	0.2147	0.9963	0.00	0.2139	0.0000	0.9992	0.7853

*For a definition of symbols used in this table, see Table 4.

Table 4. Success Probability Formulas and Results

FORMULAS

$P = C + (I \times R)$ = TOTAL SUCCESS PROBABILITY

$P_n 1 = C_n + I_n (R1_n)$ = Probability of the operator correcting his own error on a specific step

$P_n 2 = C_n + I_n (R2_n)$ = Probability of the record reader discovering an operator error on a specific step

C_n = Success probability for one step

$I_n = (1 - C_n)$ = Probability of committing an error

$R1_n$ = Probability of the operator correcting his own error

$R2_n$ = Probability of the record reader finding an operator error

n = Step number according to the task analysis

P = Probability of conducting test properly.

P_n = Probability of conducting a specific step in the task analysis properly

RESULTS

$R = 0.3681$ = Probability that the operator will complete the test without making any errors

$P1 = 0.9303$ = Probability of the operator performing the test correctly

$P2 = 0.7078$ = Probability of the record reader discovering an operator error

$P = 0.9796$ = Total probability of a functional test being performed correctly

formulas used to combine the data are shown in Table 4. Examination of the results (also in Table 4) shows that the test has a very low initial reliability (0.3681) but by the time all of the checks against unreliability have been applied, the final reliability of the test (0.9796) is respectably high.

The number arrived at in the preceding discussion, 0.9796, represents the probability that the test will be conducted in the manner intended by the test designer. To predict the successful performance of a piece of hardware, one must take into account two other factors besides the efficiency of human performance. These two factors are the reliability of the equipment itself and the validity of the test. Test validity means the probability of a properly conducted test detecting malfunctions in the part tested.

Consultation with Reliability personnel reveals that the expected reliability of solenoid valves is as follows:

High flow valves	0.9920
Low flow valves	0.9890

The reliability of the valves when combined into the multi-valve system on the vehicle is 0.8688.

Investigation has shown that no attempt has been made to quantify the efficiency with which the subsystem test examines valves and so, for purpose of the present study, the reliability of the test itself is assumed to be 1.00.

Based on this reasoning, the calculation of the probability of non-malfunctioning valves being introduced into the system test involves combining the following numbers:

Human reliability	0.9796
Test reliability	1.0000
Valve reliability	0.8688

These numbers were combined by means of standard hardware reliability techniques, with a resultant system reliability of 0.9970.

2.3.7 VALIDATION OF PREDICTIONS

An attempt was made to validate the predictions made in Section 2.3.6. This was done by examining the records of valve failures experienced subsequent to system testing. The results of this examination show that no valve failures have been experienced to date. Reliability personnel, at the request of the author, have estimated a success probability using this data to be 0.9994. The methods outlined in the foregoing discussion predict that that this number should be 0.9970. It is felt that present data, while supporting the prediction in the study, are insufficient for a definitive statement concerning the validity of the method.

SECTION 3
DISCUSSION

3.1 GENERAL

As part of this study, an investigation was made into the feasibility of applying THERP and DATA STORE to test activities. As was indicated in Section 2, evaluations of test procedures can be accomplished with reasonable speed. The results of such analyses will point out the existence of "error-prone" tasks and the probability of failure resulting from human errors during test activities.

The initial result of applying DATA STORE numbers was a low probability for an errorless test performance. Use of modified THERP techniques, however, indicated that the probability of human errors remaining uncorrected was rather low. In light of this result, it is believed that the procedure used on future studies should take this probability into account. A pure DATA STORE analysis provides the probability of no errors at all being committed during a test. What is really required is the probability that errors would be committed and not discovered. In line with this requirement, the following procedure is recommended for future quantification efforts:

a. Define the test to be evaluated.

b. Obtain an accurate task analysis of each man who assists in performing the test.

c. Review each task analysis. The purpose of this review is to determine which steps are insensitive to errors. (A step that is insensitive is one that must be performed correctly if the test is to continue, e.g., turning on a piece of equipment.) The probability of such steps being correctly performed is 1.0. (If such a procedure had been used on the study reported here, only 12 of the steps in the task analysis of Appendix B would have required evaluation.)

d. Make a DATA STORE evaluation of the sensitive steps.

e. Use THERP techniques to determine the probability of correcting errors evaluated in step d.

f. Combine the probabilities in step e into a probability of performing the test properly.

If the techniques of this paper were applied to an entire vehicle test program, one could make statements regarding the probability of an uncorrected human error remaining in the vehicle at launch and the probability of such an error causing a flight failure. This kind of data would permit an estimate of the effectiveness of the testing program and also would provide an indication of the element of unreliability added by the test program. At the present time, methods of reliability assessment assume that human actions do not contribute to vehicle unreliability unless a failure due to human error has actually occurred. Use of the methods described in this repor does not fit into the present theory of reliability assessment which stipulates, essentially, that the purpose of reliability prediction is to make a statement about the probability of a vehicle malfunctioning in the next few seconds, given "X" amount of running time on its components.

The following paragraphs describe a proposed reliability model that extends the presen theory to take into account other variables besides those presently considered.

3.2 PROPOSED RELIABILITY SCHEME

The goal of a reliability program should be a statement concerning the probability (and nature) of flight failures. This statement should take into account the following variables:

a. Design: What is the probability of perfectly functioning equipment carrying out its mission tasks? (Inherent reliability)

b. Manufacture: What is the probability that the equipment can be made exactly to the design specification?

c. Handling: What is the probability that the perfectly manufactured equipment will be transported (without degradation) to the environment in which it must carry out its duties?

To the above three basic variables, one must add a fourth which enters the picture only because of the unreliabilities of the preceding items.

d. Test Efficiency: What is the probability that test activities will discover all malfunctions, potential malfunctions, or out-of-specification conditions?

After predictions have been made of system reliability, these predictions should then be validated and upgraded by the results of actual performance of the system under consideration.

To the author's knowledge, present practice of reliability engineering makes use of two of the above variables: design information and records of actual performance. These data are used to generate two reliability assessments, which are demonstrated reliability and potential reliability. The values derived from the two sets of data are usually widely discrepant (i.e., about 40 percentage points). Using statistical methods (Bayesian theory), the two numbers can be combined into one value without, however, making use of any new data. In this system, testing does nothing other than to add running time to vehicle components.

The effects of testing on the reliability assessment should be more than a simple accumulation of running time. In the minds of the people who are responsible for launching a vehicle, testing provides the necessary confidence that there are no malfunctions in the vehicle and that it is indeed ready for its mission. The confidence that launch personnel have, is a function of the number of tests that the vehicle has successfully survived. The more tests passed, the greater their confidence.

A quantification method should be evolved which uses this fact as part of its model. That is, the probability of success at time of launch is affected as each test is completed.

The formula for Reliability might be as follows:

$$R = f\,(C\ I)$$

where

R = Vehicle reliability

C = Confidence that all components are working and are connected properly

I = Inherent reliability

Inherent reliability is essentially a definitive function that varies with the expected duration of a mission; it can range from zero to plus one

Confidence is a number that can vary from zero to one. Hence reliability is a positive number that varies from zero to one.

3.3 CONFIDENCE

The concept of confidence as treated in this paper is relatively new and, as such, more time will be devoted to its development. In the past, this concept has been

discussed but little has been done toward actually measuring it. As a result of the development of the techniques outlined in this report, it is believed that many, if not all the obstacles, have been removed from its quantification.

For purposes of quantification, confidence can be broken into the following variables:

a. Manufacture: What is the probability that the device will be exactly according to the design specification?

b. Handling: What is the probability that the equipment will be handled (processed, serviced, and tested) without damage or significant deterioration of performance.

c. Test Efficiency: What is the probability that the test program will discover all malfunctions in the equipment?

At the present time, it is quite possible to measure the first two variables through use of the data in the DATA STORE and in Rook (Reference 4).

To the author's knowledge, little or no work has been done to quantify test efficiency. However, with variables as concrete as hardware configuration, data flow, test points, and test procedure to work with, it would seem not too difficult for some knowledgeable person to devise a scheme to measure test efficiency.

In a well designed testing program, the curve of reliability should have the shape of Figure 1. As can be seen from this figure, there is an abrupt rise in the curve as each test in the prelaunch cycle is complete. If the test program is properly designed, the curve

should become asymptotic to the inherent reliability as the vehicle completes the final checks before launch. Handling of the vehicle by technical personnel will incur a risk of handling damage; hence, the curve falls slightly during the interval between tests.

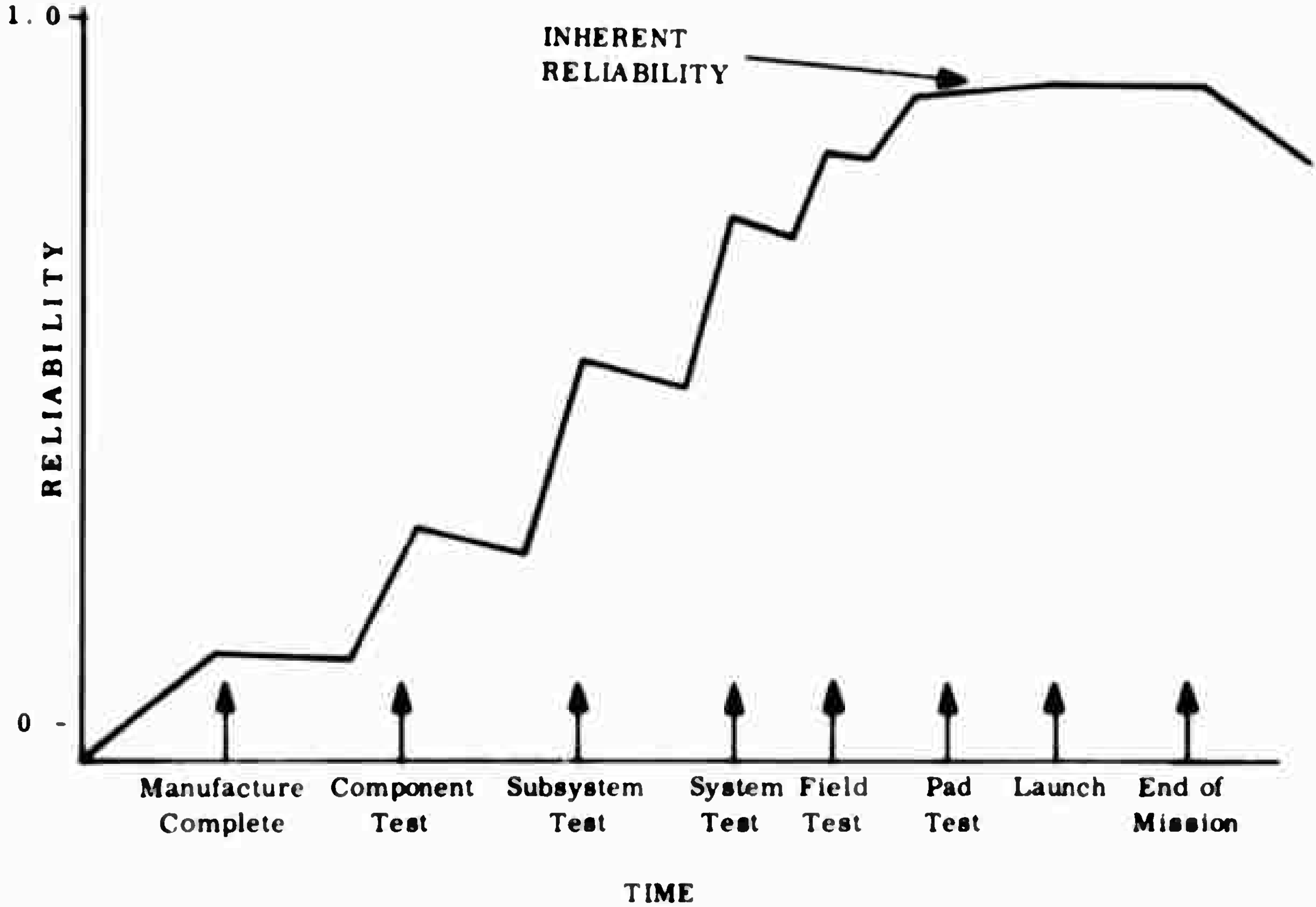

Figure 1. Curve of Expected Reliability Growth

3.4 BENEFITS

Application of the reliability scheme outlined in the preceding section could be expected to provide an assessment of the contribution of specific tests to the over-all reliability of a system. It will enable Management to eliminate tests that are not contributing

to reliability, and to see the need for additional tests. The most significant aspect of the reliability model is that it simulates actual circumstances. Application of this model to a system could be expected to result in predictions that would be accurate for the first flights as well as for the ultimate flights (as predicted by inherent reliability). This statement is possible because the model does not assume away variables (i.e., human error and test efficiency) that significantly affect reliability.

The only factor which prevents immediate application of this model to a system is the invention of a method for quantifying test efficiency. And, as stated previously, this problem should prove amenable to effort by knowledgeable personnel.

SECTION 4

RESULTS

As a result of this analysis, the following statements can be made. The importance of these statements is not so much their specific content, but rather the fact that these types of statements can be made about a test after completion of such an analysis:

a. The probability that the tester will complete the test without making a single error is 0.3681

b. The probability that the operator will complete the test properly by correcting all errors he commits is 0.9303.

c. The probability that the man checking the results of the test will detect errors made by the operator is 0.6734.

d. The probability that the vehicle will be properly tested, given the above variables, is 0.9772.

e. By combining human reliability with equipment reliability, it is possible to make the following statement: "The probability that a set of non-malfunctioning valves will enter systems testing is 0.9970."

SECTION 5

CONCLUSIONS

It is felt that the basic methods developed by Payne and Altman in DATA STORE, and by Rook and Swain in THERP, can be applied to all phases of human factors work Thus far, these techniques have been applied to electronic equipment operability (Payne and Altman); industrial production (Rook); military field operations (Swain); and, in this study, to industrial test operations It would seem but a short step to apply these techniques to human engineering of consoles and other equipments.

These methods offer human factors personnel who must work in an applied setting, the opportunity to progress from qualitative statements to quantitative statements.

The words of Swain (Reference 6) sum up the need and advantages of using these techniques rather neatly and make a fitting ending to this paper:

> "In the meantime, it is well to emphasize that THERP is strictly an empirical approach; if it enables us to make predictions sufficiently accurate for the purpose at hand, we use it. We are far from being complacent about some of the assumptions we have to make, but we have reliability problems to solve. We feel that using the data we have is better than doing nothing, thereby either (1) forcing engineers or others not trained in human factors technology to make their own estimates of human reliability, or (2) allowing system reliability equations to continue, as most do, to assume no degradation resulting from the human element."

SECTION 6

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APPENDIX A

DESCRIPTION OF METHODS OF QUANTIFYING HUMAN RELIABILITY

A-1. DATA STORE

DATA STORE is an index of electronic equipment operability developed by Daniel Payne and James W. Altman, while working at the American Institute for Research. This index contains quantitative information on the time and reliability of performing various human tasks. The individual tasks are broken up into small segments of behavior that lend themselves to general use in any situation. Examples of small segments of behavior represented in DATA STORE might be: reading a circular scale, reading a label, connecting a cable, turning a crank, positioning an object, etc. For purposes of quicker evaluation, the tasks are broken down into three categories: input or sensing tasks, mediating or deciding tasks, and output or control tasks.

A-1.1 SOURCE OF DATA

The numbers used in DATA STORE were gathered from a search of thousands of human engineering studies, most of which involved laboratory research. The error rates obtained from these laboratory studies seemed to be grossly high for a direct estimate of operational or field error rates. Apparently laboratory workers, in order to obtain more statistical confidence in their conclusions, designed tasks to get high error rates. Whereas in the operational situation, design was aimed at obtaining the lowest error rate possible. To reconcile these differences, past field studies were examined and a correction factor was generated which was then applied to all laboratory results to bring them more in line with field experience.

A-1.2 RESULTS

Since the tasks listed in the DATA STORE are not gross ones, they can be combined into units which will closely approximate almost any given task that is to be evaluated.

Reliability scores obtained through use of the DATA STORE method are the product of individual reliability estimates. A basic assumption made when using the method is that all tasks are independent of each other.

The information obtained from a DATA STORE analysis can be used to pinpoint problem areas because it provides individual scores for all tasks and their elements, as well as a total score. With this data, one can examine the total task for those elements which contribute the greatest amount to unreliability so that corrective attention can be focused on them.

Once corrective actions are proposed, a DATA STORE ANALYSIS can be performed on the changes to determine the alteration in task reliability to be expected from the proposed changes. For further information, see Payne and Altman (Reference 2).

A-2. THERP

THERP (Technique for Human Error Rate Prediction) is a method for performing a human factors reliability analysis which has been used since 1961 by the Reliability Department at Sandia Corporation. The analysis has been employed primarily to provide quantitative predictions of degradation to a man/ machine system resulting from human errors. Application of the THERP method involves the following steps:

a. Define the system or subsystem failure to be evaluated.

b. Identify all important human operations performed and their relationships to system tasks and functions.

c. Predict error rates for each human operation.

d. Determine the effect of human errors on the system.

e. Recommend changes as necessary to reduce the system or subsystem failure rate as a consequence of the estimated effects of the changes.

The THERP method revolves around the construction of a logic box diagram of paths to system success. Human errors require shifting to alternate paths. That is, given a human error, what additional actions are necessary to correct that error if the system is to complete its mission successfully? Each branch of the logic box must then be assigned a probability of successful completion. Assignment of values to each branch must take into account problems of dependence versus independence of events, and the effects of stress, climate, motivation and a host of other variables which affect human performance and decision making. The model can easily be expanded to include equipment reliability predictions in order to facilitate tradeoffs between manual or automatic modes of operation. Thus it can be a valuable tool in functions allocation early in the life of a system.

For further information, see Rook (Reference 4) and Swain (Reference 5).

APPENDIX B

TASK ANALYSIS OF PNEUMATICS FUNCTIONAL TEST*

The following material is a reproduction of the task analysis used in this study. To the left of each step can be found the calculated DATA STORE reliability for that step. Numbers indented from the left side are values for parts of a step. The value for the total step is usually obtained by multiplying the values for all parts of the step.

Reliability	Step
0.9960	1. Turn on power to oscillograph recorder (if not already on):
0.9987	a. Throw ON/OFF toggle switch up.
0.9973	b. Push red button on console (1 of 6 buttons).
0.9886	2. Connect test cables to the pressure transducers and solenoids (19 cable sets):
0.9989	a. Position test cables.
0.9994	b. Connect cables.
0.9722	3. Connect the nitrogen high-pressure-leak-rate system to the fill line.
0.9952	a. Short pneumatics line to Millapore filter:
0.9989	(1) Remove cap.
0.9988	(2) Put on seal ring.
0.9991	(3) Put pneumatics line over connection.
0.9996	(4) Start connection with fingers.
0.9988	(5) Tighten with two wrenches (7/8 inch, open-end).
0.9952	b. Millapore filter:
For reliability values, see step 3a.	(1) Remove cap on filter fitting.
	(2) Put on seal ring.
	(3) Put pneumatics line over connection.
	(4) Start connection with fingers
	(5) Tighten connection with two wrenches.

*This test is defined by Standing Instruction 238131, Section 3.3

Reliability	Step
0.9952	c. Filter to floor (line about 5 feet long). Same as in step 3b.
0.9864	d. Pneumatics line to Schrader valve on vehicle (line about 15 feet long):
0.9944	(1) Attach the long line at the AGE end.
0.9972	(2) Purge the system:
0.9976	(a) Set the regulator at 100 psi.
0.9996	(b) Let gas flow through system for short period of time.
0.9948	(3) Attach the pneumatics line to the vehicle Shrader valve:
0.9993	(a) Remove the cap on the Shrader valve.
0.9992	(b) Remove the cap on the pneumatics line.
0.9963	(c) Proceed as described in steps 3a (2) through 3a (5).
0.9745	4. Open the nitrogen line valve:
0.9981	a. Check gauge to determine what pressure is in the source.
0.9863	b. Crack the nitrogen valve and watch the pressure mount on gauge to 5500 psi.
0.9977	5. Open the nitrogen shutoff valve:
0.9992	a. Check that the vent valve is closed.
0.9985	b. Open the nitrogen valve.
0.9985	6. Open the nitrogen high-pressure-leak-rate system shutoff valve:
	a. Crack the valve slowly, then open it (twist counterclockwise)
0.9991	7. Open the Shrader valve on the vehicle:
	a. Using open-end wrench, turn valve counterclockwise two and one-half turns.

Reliability		Step
0.9985	8.	Open the leak-rate shutoff valve on the console in the test control room:
	a.	Twist the valve counterclockwise.
0.9985	9.	Open the nitrogen high-pressure-leak-rate system shutoff valve:
	a.	Twist the valve counterclockwise.
0.9711	10.	Set up the oscillograph recorder (to be done prior to each test requiring its use):
0.9990	a.	Flip POWER ON toggle switch up. Allow one hour for warmup.
0.9978	b.	Push the POWER ON indicator button. Check to see if the indicator next to it goes on. If not, repeat step 10a.
0.9990	c.	Turn on the power supply:
	(1)	Flip toggle switch up.
0.9827	d.	Adjust power to 5 volts:
0.9995	(1)	Adjust coarse potentiometer.
0.9832	(2)	Check reading on meter.
0.9900	e.	Check that the timing lines on the recorder are correct:
0.9982	(1)	Set selector (4-position switch) on 1 line per second.
0.9929	(2)	Run short record check to determine that one timing line per second is indicated:
0.9996	(a)	Check manual toggle switch
0.9965	(b)	Push 1 SEC ON/ OFF button.
0.9968	(c)	Turn off recorder.
0.9934	f.	Set up the proper traces on the recorder:
0.9980	(1)	Pull the recorder half way out of the cabinet.
0.9999	(2)	Open the access door on top of the recorder box.

Reliability	Step
0.9997	(3) Check the listing of the light spots desired for functions to be read out.
0.9997	(4) If not set up correctly, disconnect or connect proper pins with adjustment tool (maximum of four pins: two put in, two pulled out).
0.9993	(5) Check location of spots of light on the record.
0.9999	(6) If not correct, remove adjustment tool.
0.9983	(7) Move lights to correct position on the chart.
0.9999	(8) Move extra spots off chart.
0.9999	(9) Replace adjustment tool.
0.9999	(10) Close access door.
0.9980	(11) Push box back into console.
<u>0.9038</u>	11. Calibrate the recorder:
0.9993	a. Check that the timing mark selector is set correctly (4-position selector).
0.9976	b. Set up the desired pressure on the gauge.
0.9993	c. Record pressure used on record paper.
0.9965	d. Push 1 SEC button and ON/ OFF button to start record.
0.9968	e. Push ON/ OFF button to stop record.
0.9999	f. Check the record for proper pressure indication.
0.9309	g. Return to step 11b and repeat steps 11b through 11f in 10-pound increments until the low-pressure regulator locks out; i.e., the line shows no change between the last pressure and the present reading. (Range of values should be from zero to 70 pounds pressure.)
0.9917	h. When the low-pressure regulator locks out, switch Millipore filters:
0.9985	(1) Lower all pressure in system to ambient by opening leak-rate valve until gauge reads zero.

Reliability	Step
0.9996	(2) Push one or two solenoid buttons at random to vent off any residual pressure in the system.
0.9936	(3) Switch the Millapore filter from the low-pressure to the high-pressure system:
0.9984	(a) Remove one fitting with two wrenches.
0.9952	(b) Fasten filter to bulkhead fitti..g.
0.9930	(c) Fasten new filter to high-pressure fitting (see step 3).
0.9930	(d) Fasten filter to pneumatics line to vehicle.
0.9799	i. Return to step 11b and continue calibration of the high-pressure regulator pressure in increments of 100 pounds until regulator locks out. Usually two readings are required: 400 psi and 500 psi.
0.9988	j. Check the record to ensure proper operation of the regulators.
<u>0.9992</u>	12. After calibration of the recorder, detach the record and store it.
	a. Rethread the paper in the recorder.
<u>0.9900</u>	13. Pressurize the system with nitrogen:
0.9976	a. Open the leak-rate high-pressure regulator.
0.9924	b. Observe the high pressure gauge.
<u>0.9929</u>	14. Check the pressure downstream of the regulators.
For reliability values, see step 10f(2)	a. Take an oscillograph reading to verify the pressure:
	(1) Push 1 SEC button.
	(2) Push ON/OFF button.
	(3) Push ON/OFF button again to stop record.
	b. Check the record to verify proper lockout pressures; i.e., no change in lockout lines.

Reliability	Step
0.9976	15. Turn on the high- and low-pressure stabilization control POWER ON switches:
0.9977	a. Flip two toggles switches up.
0.9999	b. Observe indicator going on above switch.
0.9865	16. Purge high- and low-flow nozzles:
0.9970	a. Press solenoid microswitches (16 switches) for no longer than a few seconds each.
0.9999	b. Observe indicator on each switch as it is pressed and listen for swish of gas.
0.9901	17. Pressurize the system to 3500 psi:
For reliability values, see step 11b, 11c.	a. Open the leak-rate high-pressure regulator.
	b. Watch pressure gauge rise until it reads 3500 psi.
	c. Observe traces on the recorder. Traces must rise above lockout levels:
	(1) Write pressure on the record.
	(2) Press 1 SEC button.
	(3) Press ON/ OFF button to start record.
	(4) Press ON/ OFF button to stop record.
0.9908	18. Set up the timers on the calibration panel (to be done twice during the test for regulators for solenoids):
0.9974	a. Check that paper supply on recorder is adequate.
0.9997	b. Check that delay timer is set for more than 0.15 second.
0.9990	c. Check that recorder timer is set to read more than 0.15 second.
0.9990	d. Check that solenoid timer is set to read more than 0.80 second.

Reliability	Step
0.9967	e. Check that the settings on record speed controls are correct:
0.9984	(1) Observe 4-position dial (set at 100).
0.9983	(2) Observe six-button complex (button for 16 inches should be depressed).
0.9990	19. Flip solenoid toggle switch to the timer position (down):
	a. Observe indicator going on.
0.9742	20. Check Standing Instruction 238131, Section 3.3 for proper combination of solenoid switches.
0.9845	21. Record combination of solenoids on record.
0.8996	22. Press combination of solenoid buttons specified in SI 238131 (Section 3.3) and hold them down.
0.9738	a. Input from SI.
0.9239	b. Press and hold buttons.
0.9703	23. Press TIMER START button (at times, two men are required to accomplish this task).
0.8119	24. Repeat steps 22 and 23 for all 20 combinations specified in the SI:
0.9698	a. Check that pressure remains at 3500 psi throughout testing.
0.8372	b. See steps 20 through 23.
0.9971	25. Vent the system pressure to 1000 psi:
0.9976	a. Close leak-rate high-pressure regulator.
0.9999	b. Press solenoids on high-pressure side.

Reliability	Step
0.9996	c. Observe pressure decay on gauge. When pressure is zero, release solenoid buttons.
0.9976	d. Adjust leak-rate regulator to build pressure up to 1000 psi.
<u>0.8119</u>	26. Repeat the sequence of solenoid tests (steps 20 through 25) for 20 sequences.
0.9971	27. Vent system to ambient:
0.9972	a. Open leak-rate valve.
0.9999	b. Press solenoids at random.
<u>0.9975</u>	28. Shift recorder speed to a slower rate:
0.9982	a. Move selector switch to 10 degrees (4-position switch).
0.9993	b. Use a pen to identify the record.
<u>0.9930</u>	29. Run off a short strip of record:
0.9965	a. Press ON/ OFF button to start the recorder.
0.9965	b. Press ON/ OFF button to stop the recorder.
<u>0.9992</u>	30. Remove the record and store it.
<u>0.9991</u>	31. Rethread a new record in the recorder.
<u>0.9976</u>	32. Repressurize the system to 3500 psi:
See step 3d(2) and 3d(9) for reliabilities	a. Open the regulator valve.
	b. Watch gauge until it reads 3500 psi.
	c. Adjust valve to hold this pressure.

Reliability	Step
0.9990	33. Check the position of the solenoid switch.
	a. Switch should be in the down position (on TIME position).
0.9934	34. Check and adjust the recorder channels (See steps 10e and 11g).
0.9991	35. Check SI 238131 for proper solenoid button.
0.9993	36. Record solenoid "A" number on recorder chart.
0.9956	37. Hold down proper solenoid button (these buttons do not follow in order of console placement).
0.9985	38. Press TIME START button on recorder console and release both buttons.
0.9864	39. Perform steps 35 through 38 for all 16 solenoids.
0.9898	40. When test is complete at high pressure, run recorder at slow speed to identify end of record:
0.9924	a. Reset speed dia (4-position dial).
0.9990	b. Flip toggle switch to MANUAL.
0.9994	c. Write identification on record.
0.9965	d. Press ON/ OFF button to start record.
0.9965	e. Press ON/ OFF button to stop record.
0.9947	41. Vent the system to 1000 psi:
For reliabilities	a. Close leak-rate high-pressure regulator.
see step 25	b. Check recorder to determine that it is in manual mode.
	c. Press solenoid buttons at random to speed venting of system.

Reliability		Step
	d.	Observe decay of pressure on gauge.
	e.	Adjust leak-rate regulator to provide 1000 psi in system.
	f.	Check gauge reading for 1000 psi.
0.9968	42.	Check to ensure that recorder is ready for low-pressure run:
0.9990	a.	Toggle switch in timer mode.
0.9984	b.	Speed setting on 64 lines per second.
0.9994	c.	Identify run on record with pen.
0.8859	43.	Repeat testing of solenoids (steps 36 through 40) for 16 switches.
0.9990	44.	Put recorder toggle switch in MANUAL position.
0.9971	45.	Vent system to ambient:
0.9976	a.	Open leak-rate regulator valve.
0.9995	b.	Press high-pressure solenoid buttons at random until gauge reads zero pressure.
0.9992	46.	Detach record and store it.

END OF TEST